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Impact of nitrogen additions on soil microbial respiration and temperature sensitivity in native and agricultural ecosystems in the Brazilian Cerrado

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ABSTRACT

Soil microbial respiration (SMR[1]) is a major flux of CO_2 from terrestrial ecosystems into the atmosphere, which depends on several abiotic factors, including soil temperature and nutrient availability. A nutrient of great interest in soil ecology is nitrogen (N) because of its use in agriculture and an expected increase of depositions in soils. Models on the relationship between SMR and temperature may be able to describe the effects of N addition on the temperature sensitivity of soil respiration (Q_{10}[2]). Hence, this study aimed to investigate the effects of N addition on SMR and Q_{10} values in soils of native Brazilian Cerrado (NC[3]), and of an agricultural ecosystem (AE[4]) cultivated over the past 17 years. SMR was stimulated by N additions (100 and 200 mg N kg dwt soil^{-1}) in samples of Cerrado sites depending on the land use type and temperature assessed. The addition of 200 N kg dwt soil^{-1} to NC showed higher SMR values at 25 °C compared to soil without N input, whereas the same happened in AE at 30 °C. Overall, NC presented higher Q_{10} values than AE. N inputs increased Q_{10} in the Cerrado sites. In NC, the highest Q_{10} value occurred when 200 mg N kg dwt soil^{-1} was added to soil, whereas in AE the greatest value was observed for a lower dose (100 mg N kg dwt soil^{-1}). This study shows that N additions to tropical soils alter Q_{10} values depending on dose and land use. These are important findings to compare the fragility of pristine and cultivated Brazilian Cerrado ecosystems in the perspective of climate change.

1. Introduction

Terrestrial ecosystems play a key role in the carbon dioxide (CO_2) efflux between soil and atmosphere (Crowther et al., 2015; Kirschbaum, 1995; Litton et al., 2011; Stoffel et al., 2010). On a global scale, the soil CO_2 efflux resulting from roots and soil microorganism's metabolism, commonly referred to as soil respiration, is considered to be the second largest carbon (C) flux (Raich and Potter, 1995; Schlesinger, 1977). With the phenomenon of global warming, research on the positive soil CO_2 feedback to the atmosphere caused by a warming-induced increase in soil respiration has received a great concern (Crowther et al., 2016; Davidson and Janssens, 2006; Jiang et al., 2015). However, little has been reported over soil microbial respiration (SMR) in tropical soils, including savanna ecosystems. SMR is a substantial carbon efflux affecting atmospheric CO_2 concentrations, which is accounted for approximately 91 Pg C yr^{-1} (Hashimoto et al., 2015). Therefore, small changes in the factors controlling SMR may result in high net CO_2 effluxes to the atmosphere, thus, contributing to soil C losses and intensifying climate change effects (Crowther et al., 2015; Erhagen et al., 2015; Raich and Schlesinger, 1992).

SMR depends on many factors, such as soil moisture, temperature and organic substrate availability (Raich and Schlesinger, 1992; Yonemura et al., 2009). However, the temperature is described as the primary factor affecting microbial activity and soil respiration rates (Fang and Moncrieff, 2001; Janssens and Pilegard, 2003; Koch et al., 2007). Many reports have shown an exponential correlation between soil respiration and temperature, but there is still no consensus on the exact form of this relationship in tropical soils (Fierer et al., 2006; Karhu et al., 2014; Lloyd and Taylor, 1994) due to the heterogeneity and complexity of soils and ecosystems. The temperature sensitivity (Q_{10}), measured by the response of soil respiration to an increase of 10 °C in soil temperature, is an important indicator for assessing the fragility of ecosystems to abiotic factors (Hursh et al., 2017; Liang et al., 2015; Qi et al., 2002). Few experiments have explicitly determined the

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[1] SMR: Soil microbial respiration.
[2] Q_{10}: Temperature sensitivity of soil microbial respiration.
[3] NC: native Brazilian Cerrado.
[4] AE: Agricultural ecosystem.

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Q_{10} of SMR and particularly between 10 and 30 °C (Hamdi et al., 2011). Many studies have been carried out measuring the Q_{10} factor in different ecosystems (Crowther et al., 2016; Davidson and Janssens, 2006; Jenkins and Adams, 2011; Peng et al., 2009). Nevertheless, there is a shortage of studies on tropical Brazilian soils (Vinhal-Freitas et al., 2013).

Soil microbial activity depends on quantity and quality of the soils organic matter (Liu et al., 2016; Sjögersten and Wookey, 2002; Yuste et al., 2003). Likewise, the microbial use of C sources is also dependent on nutrient availability, such as nitrogen (N) (Cao et al., 2011; Fang et al., 2017; Gnankambary et al., 2008). Soil microorganisms actively participate in organic matter decomposition and regulate nutrient cycling (Ilstedt and Singh, 2005; Mary et al., 1996). Nitrogen availability is particularly important due to its role in controlling soil microbial activity, as it is required in the microbial metabolism (Galloway et al., 2004). Nitrogen is an essential compound in the formation of amino acids, proteins and nucleic acids (Harper, 1987; Miflin and Lea, 1976). This nutrient cycle is very dynamic; therefore, soil N losses are expected due to the processes of denitrification, erosion, and volatilization (Galloway et al., 2004; López-López et al., 2012). Hence, N availability to microorganisms controls the process of soil organic matter transformation in many ecosystems (Allison et al., 2008; Bayer et al., 2000).

Terrestrial ecosystems have received more than 50 kg accumulated N ha^{-1} between 2000 and 2010 (Peñuelas et al., 2013). Nitrogen deposition is an increasing global environmental problem that occurs mostly due to anthropogenic causes and agricultural practices, such as fertilization (Gruber and Galloway, 2008; Peng et al., 2009; Tian and Niu, 2015). Chronic N deposition often results in nitrate loss and base cation depletion occasioning in soil acidification and biomass reduction, which pose a threat to biological diversity and terrestrial ecosystem functioning (Corre et al., 2003; Gaudio et al., 2015; Tian and Niu, 2015).

In the context of global warming, one of the main challenges is to understand how this increasing atmospheric N inputs to terrestrial environments influences soil C dynamics and soil respiration (Fang et al., 2017; Tu et al., 2013). Anthropogenic N deposition can lead to an N saturated state, what may also alter the efficiency of soil C use and decomposition processes (Corre et al., 2003; Saiya-Cork et al., 2002); directly affecting SMR. Therefore, the effects of N deposition on SMR can greatly change the direction and extent of the C balance response (Ramirez et al., 2010). In the Brazilian Cerrado biome, the effects of N deposition on the temperature sensitivity of SMR, Q_{10}, have never been reported, as well as whether it would have a higher impact on native forest or agricultural soils.

The Brazilian Cerrado covers over 200 million hectares and is equivalent to 22% of the country's territory (Batlle-Bayer et al., 2010; Klink and Machado, 2005). Moreover, the region is a global biodiversity hotspot (Carranza et al., 2014). The ongoing conversion of this ecosystem into agricultural lands is of high concern (Maia et al., 2013; Rada, 2013). Land use changes are reported to greatly affect SMR and the C cycle, altering the CO_2 efflux to the atmosphere and soil C stocks (Gong et al., 2014; Jiang et al., 2015; Zhang et al., 2015). Furthermore, Brazilian Cerrado soils are acidic, nutrient-poor and characterized by low cation and P availability (Copeland et al., 2012; Costa, 2011; Rada, 2013). Under these conditions, an increase on N deposition can alter soil pH and, therefore, increase aluminum toxicity and decrease cation and P availability (Copeland et al., 2012; Saiya-Cork et al., 2002; Tian and Niu, 2015). There are limited studies on the effects of nutrients on Q_{10} of SMR (Erhagen et al., 2015; Liu et al., 2016; Tu et al., 2013). In this sense, research on these processes and particularly in Brazilian Cerrado soils are relevant. Therefore, this research aims to: (1) determine the SMR under different temperature conditions and N additions; and (2) evaluate the effects of N addition on soil Q_{10} indexes in pristine and cultivated Brazilian Cerrado sites.

2. Material and methods

2.1. Sampling sites

The study was performed in the Cerrado region in Minas Gerais state, southwest in Brazil. The climate of this region is classified as "Cwa" according to Köppen (Alvares et al., 2013), characterized by a well-defined dry season during fall-winter (April to September) and a hot and rainy season during spring-summer (October to March). The mean annual precipitation is in between 1500 and 1600 mm, with 50% falling during the rainy season from December to February. The mean annual air temperature during the winter season is of 18 °C whereas in summer it is approximately of 23 °C with maximum temperatures ranging from 28 to 29 °C (Silva et al., 2003). Soil sampling was performed in sites of native Cerrado (NC, 19°20′42″S and 48°0′59″W, 975 m) and agricultural ecosystem (AE, 19°20′54″S and 48°01′06″W, 948 m). Representative plant species from NC can be found in Vinhal-Freitas et al. (2013). The studied AE was an area recently gained by land use conversion from a forest ecosystem, cultivated with soya in the past 17 years and alternating with corn each 5-year.

2.2. Soil sampling

The soil sampling in AE was performed just before soya plantation in November 2012. The soil in the study area was classified as clayey Oxisols (Typic Acrustox) according to the USA Soil Taxonomy (USDA, 1992). Soil samples from each study area were collected during the rainy season from the top 0–5 cm of soil. In each area, three points were sampled within roughly a 1 ha area (as can be seen by the coordinates). Three subsamples of 600 cm^2 (20 cm × 30 cm), spaced 5 m apart, were randomly collected from each point to form a composite sample, summing three field samples per area studied. The samples were conditioned in sealed plastic bags and transported to the laboratory where they were immediately sieved (< 3 mm), stored and kept in a refrigerator at 4 °C until analyses were performed. SMR incubation tests were initiated within two days.

2.3. Soil characterization

Soil physical and chemical characterization analysis was performed for each study area. Particle size distribution was determined in air-dried samples (< 2 mm) using the pipette method (Gee and Or, 2002) and the gravimetric water content by oven drying soil samples (20 g) for 24 h at 105 °C. The following chemical analyses were carried out: pH in water (1:2.5 fresh soil: water slurry); soil organic carbon (SOC) using the potassium dichromate heating method (Yeomans and Bremner, 1988); total nitrogen (TN) using the Kjeldahl method (Jones, 1991); available phosphorous (P) and potassium (K^+) were extracted in acid solution (0.05 M HCl and 0.0125 M H_2SO_4) and quantified using a colorimetry assay and flame spectrophotometry respectively (Tedesco et al., 1995), employing wet-sieved soil samples. Microbial biomass carbon (MBC) was extracted by an irradiation-extraction method using a potassium sulfate solution according to Ferreira et al. (1999). Differences in C concentration between irradiated and non-irradiated extracts were used to determine MBC (Vance et al., 1987). The carbon content of soil samples was obtained by potassium dichromate reaction with s-diphenylcarbazide (Cai et al., 2011) using a spectrophotometer (Biomate 3, Thermo Fisher Scientific, Waltham, MA) at 540 nm.

2.4. Nitrogen addition and temperature assays

Treatments with N addition were performed in portions of 100 g of fresh, moist soil (40% water holding capacity (WHC)) placed in 500 mL hermetically sealed flasks. Subsequently, the samples were adjusted to a

WHC of 60%, which is considered to be an optimum for microbial respiration (Vanhala et al., 2008), by adding distilled water and/or an N stock solution. An aliquot of this source solution was added to the samples resulting in doses of 100 and 200 mg N kg dry soil^{-1}. Controls received only distilled water. The liquids were added through carefully pipetting (Gilson pipette P1000) into the soil portions. Soil samples were then incubated under controlled temperatures of 10 °C, 20 °C, 25 °C and 30 °C ± 0.1 °C for 21 days. Hence, the assays resulted in 2 sites × 3 doses × 4 temperatures with 3 replicates (field samples), totaling in 72 experimental units (flasks).

2.5. Soil microbial respiration

SMR measurements were estimated by the amount of CO_2 released in flasks after 3, 7, 14 and 21 days of incubation (Stotzky, 1965). An alkaline solution (10 mL of 1 M NaOH) was pipetted into a plastic cup (50 mL) which was then placed on top of the soil sample and used to capture CO_2 emissions as Na_2CO_3. Blanks consisted of empty flasks with 1 M NaOH but no soil. After the incubation, NaOH was titrated after 3, 7, 14, and 21 days with 0.5 M HCl after the addition of 1 M $BaCl_2$ (5 mL) and phenolphthalein indicator (1%). The hydroxide solution was renewed after each titration. The accumulated CO_2-C was obtained by adding the means of each period for each flask. The cumulative SMR at the end of each period was expressed as μg CO_2-C g dwt soil^{-1}, and the SMR rate was obtained by dividing the cumulative value per period of incubation.

2.6. Temperature sensitivity of soil respiration (Q_{10})

Mathematical models, such as the van't Hoff (1884) and Arrhenius (1889) equations, are often used to determine the temperature sensitivity of soil respiration (Q_{10}) (Jenkins and Adams, 2011; Lloyd and Taylor, 1994; Qi et al., 2002). These equations were applied to the SMR rates obtained in each studied area and N treatment to investigate their applicability to Brazilian Cerrado soils when deriving Q_{10} values.

The equations used in this study to describe the Q_{10} of SMR were as follows:

van't Hoff (1884)

$$y = ae^{bT} \quad (1)$$

where y is SMR rate (μg CO_2-C g dwt soil^{-1} d^{-1}); T is soil temperature in Celsius (C), and; a and b are regression coefficients.

Q_{10} from the van't Hoff equation, which is the multiplier for the SMR for a 10 °C increase in temperature, was calculated by the following equation:

$$Q_{10} = e^{10b} \quad (2)$$

where b is obtained from Eq. (1).

Arrhenius (1889)

$$Y = Ae^{\frac{-Ea}{RT}} \quad (3)$$

where Y is SMR rate (μg CO_2-C g dwt soil^{-1} d^{-1}); A is the coefficient from linear equation obtained from the Y natural logarithm in relation with absolute temperature ($1/T$) in Kelvin (K). Ea is the activation energy, which results from the multiplication of the coefficient b with the gas constant R (8314 J K^{-1} mol^{-1}), and; T is the average soil temperature in Kelvin (K).

Q_{10} from the Arrhenius equation was then calculated by:

$$Q_{10} = e^{\frac{10Ea}{RT(T+10)}} \quad (4)$$

where Ea is obtained from Eq. (3).

2.7. Statistical analysis

SMR, cumulative SMR and SMR rate values were used to verify the microbial response to temperature and nitrogen additions in the two studied ecosystems using different statistical procedures. The cumulative SMR of 3, 7, 14 and 21 days was used to assess the differences between the two sites under four incubation temperatures, with standard deviation determination for each period followed by ANOVA. SMR after 21 days of incubation was used to investigate the microbial response to nitrogen additions under different temperatures performing ANOVA and averages comparison between ecosystems, nitrogen doses, and temperature. The SMR rate of 21 days was used to test van't Hoff (1884) and Arrhenius (1889) models with regards different temperatures and nitrogen additions in each site, with equation parameters tested with the software SigmaPlot 12.0 (Systat Software, Inc., San Jose, CA, USA). Regression parameters from each equation were analyzed for a significance level of $P < 0.05$. Q_{10} values were determined for each repetition using the parameters of each model. ANOVA was carried out to evaluate the Q_{10} differences between sites, nitrogen doses and model applied. Averages between treatments were compared by Tukey's Test ($P < 0.05$). ANOVAs were conducted by the software SPSS 13.0 for Windows (SPSS Inc., Chicago, IL, USA).

3. Results

The physicochemical properties of soils from the studied Cerrado areas are presented in Table 1. The sand, clay and silt content of soils are similar between both sites because areas are located within the same edaphoclimatic conditions. Low pH was observed in NC in comparison with AE. NC had a greater SOC and MBC concentration than AE. Soil total nitrogen concentration was also higher in NC, whereas phosphorus (P) and potassium (K) availabilities were lower than in AE. In addition, C:N ratio was lower in NC than in AE.

The response of SMR to temperature increases was assessed during 21 days of incubation (Fig. 1). Results show that NC had a higher response to temperature increases in comparison with AE. The differences between ecosystems were observed only in the temperatures of 20, 25 and 30 °C. The higher temperatures (25 and 30 °C) gradually amplified the differences in accumulated SMR between the sites.

Cumulative SMR values at each site were used to assess the response of soil microorganisms to N additions (Table 2). In NC, the greatest cumulative SMR was observed at 25 °C under 200 mg N kg dwt soil^{-1}, with an average of 1075 ± 124 μg C-CO_2 g dwt soil^{-1}. Alternatively, in AE, the largest cumulative SMR for the same N dose was observed at 30 °C, with average 527 ± 50 μg C-CO_2 g dwt soil^{-1}. The highest significative differences between N doses were observed at 25 °C and 30 °C for NC and AE, respectively. At 10 °C and 20 °C, for both sites, no significant changes in SMR after N addition were detected.

An exponential trend can be observed in the SMR-temperature relationship (Fig. 2). The slope of trend curves is higher for samples in which N amendments were performed. Both van't Hoff and Arrhenius models were applied to the Cerrado soil samples with and without N

Table 1
Soil characteristics for NC and AE ecosystems at 0–5 cm depth.

Property[a]	NC	AE
Sand (g kg^{-1})	135	140
Clay + Silt (g kg^{-1})	865	860
pH water (2:1)	4.3 ± 0.1	6.5 ± 0.0
SOC (g kg^{-1})	48.2 ± 7.5	30.3 ± 4
MBC (mg kg^{-1})	559	297
TN (g kg^{-1})	3.24 ± 0.15	1.93 ± 0.03
P (mg kg^{-1})	1.3 ± 0.3	8.29 ± 0.0
K (mg kg^{-1})	57.9 ± 4.9	106.0 ± 0.0
C:N	14.9	15.7

[a] SOC, soil organic carbon. MBC, microbial biomass carbon. TN, total nitrogen. P, phosphorus. K, potassium. C: N, carbon: nitrogen ratio. Values correspond to the mean and standard deviation of each property.

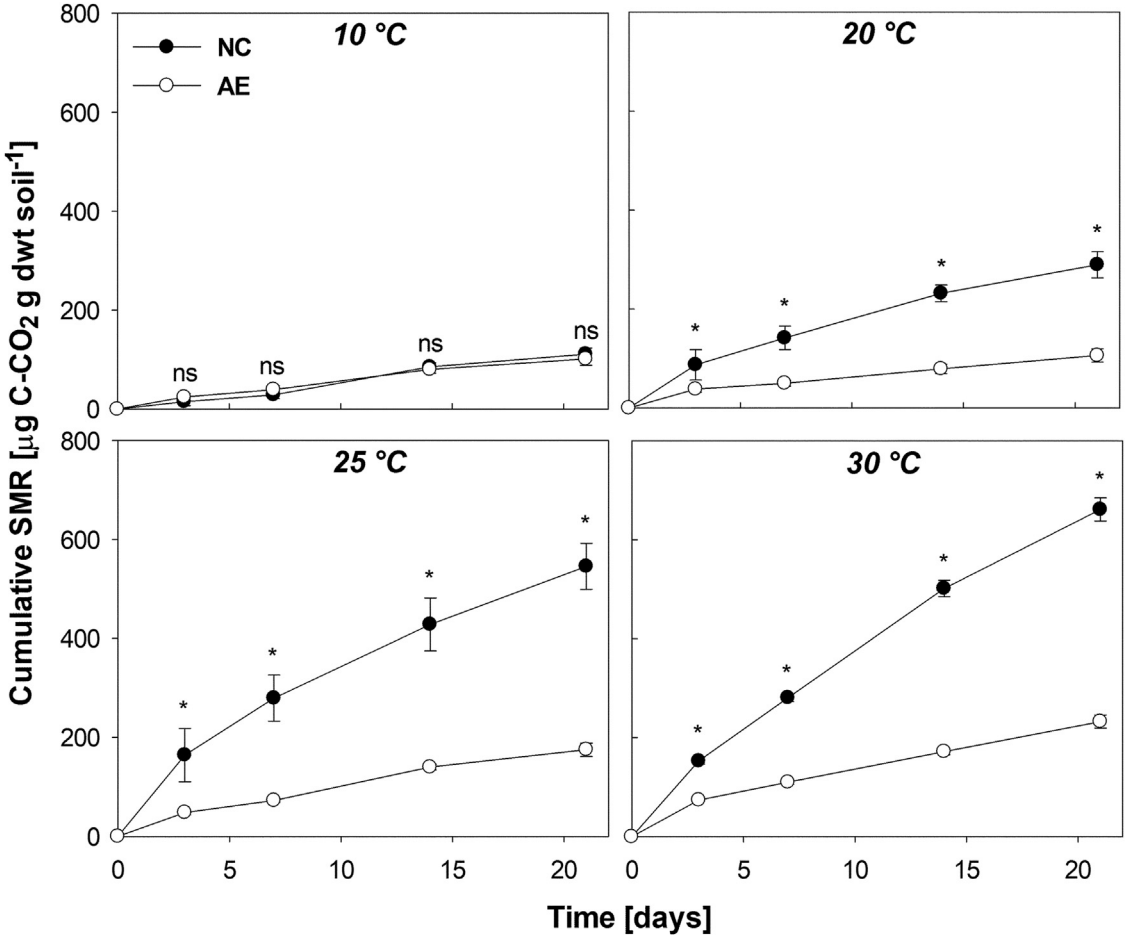

Fig. 1. Responses of soil microbial respiration (SMR) to temperature incubations (10 °C, 20 °C, 25 °C and 30 °C) in untreated soil samples of native cerrado (NC) and agricultural ecosystem (AE) for 21 days of incubation. Error bars indicate the standard deviation of SMR for each incubation period. Stars (*) denote significant differences between sites in each incubation period by Tukey's test at 5% significance level.

Table 2
Average cumulative SMR after incubation at 10, 20, 25 and 30 °C during 21 days of controls and N treatments for NC and AE ecosystems.

Site	N (mg kg dwt soil^{-1})	SMR (µg CO_2-C g dwt soil^{-1})			
		10 °C	20 °C	25 °C	30 °C
NC	0	111 aA(d)	289 aA(c)	545 aC(b)	660 aB(a)
	100	137 aA(d)	319 aA(c)	647 aB(b)	765 aA(a)
	200	134 aA(d)	324 aA(c)	1075 aA(b)	782 aA(a)
AE	0	101 aA(b)	106 bA(b)	175 bA(ab)	232 BCE(a)
	100	132 aA(b)	163 bA(b)	214 bA(b)	403 bB(a)
	200	155 aA(c)	166 bA(bc)	254 bA(b)	527 bA(a)

Different letters represent significative differences by Tukey's test ($P < 0.05$). In each column, lowercase letters show differences between averages in each temperature inside each dose between the sites. In each column, capital letters show differences between averages in each temperature inside each site between the doses. In each row, lowercase letters between parentheses show differences between averages in each dose inside each site between the temperatures.

treatments (Fig. 2). The results showed that the NC model had the highest fit values ($R^2 > 0.83$) and that for AE the fit values for all treatments were always lower when compared to NC (Table 3). For both models, the N addition of 200 mg N kg soil^{-1} decreased the fit values. The addition of 100 mg N kg soil^{-1} caused no change compared to control for both sites. The results showed that the fit values indicate similarity of the models.

The Q_{10} values of both sites ranged from 1.4 to 2.7, irrespective of the model used to fit the data (van't Hoff or Arrhenius) (Fig. 3). The values did not significantly change between the models applied ($P > 0.05$). There were significant differences between NC and AE, with the highest Q_{10} values in NC. The results show that N addition changed Q_{10} values with different responses for each land use type and N dose. In NC, an increased Q_{10} value was only observed with the addition of 200 mg N kg dwt soil^{-1}. In AE, the addition of 100 mg N kg dwt soil^{-1} increased the Q_{10} value significantly when compared to the control treatment. It is relevant to note that even with N additions, the difference in Q_{10} between land uses remains.

4. Discussion

This study is one of the first reports addressing the temperature sensitivity of SMR (Q_{10}) in Brazilian Cerrado sites and the impact of N addition to soils on Q_{10} values. The assessed ecosystems are rather different in terms of chemical properties. Cerrado soils usually have low pH (Klink and Machado, 2005; Rada, 2013), what was also observed in this study (Table 1). On the other hand, AE presented a higher pH value than NC, which can be explained by liming practices in the study area. Liming as well as fertilizing are standard practices in the management of agricultural Cerrado soils (Batlle-Bayer et al., 2010; Klink and Machado, 2005). Likewise, elevated P and K levels present in AE soil compared to NC are related to fertilization practices. Higher values of TN were found in NC due to the higher soil organic matter content of this ecosystem (Vinhal-Freitas et al., 2017). The native Cerrado site also presented higher MBC values than AE. Native Cerrado soils usually

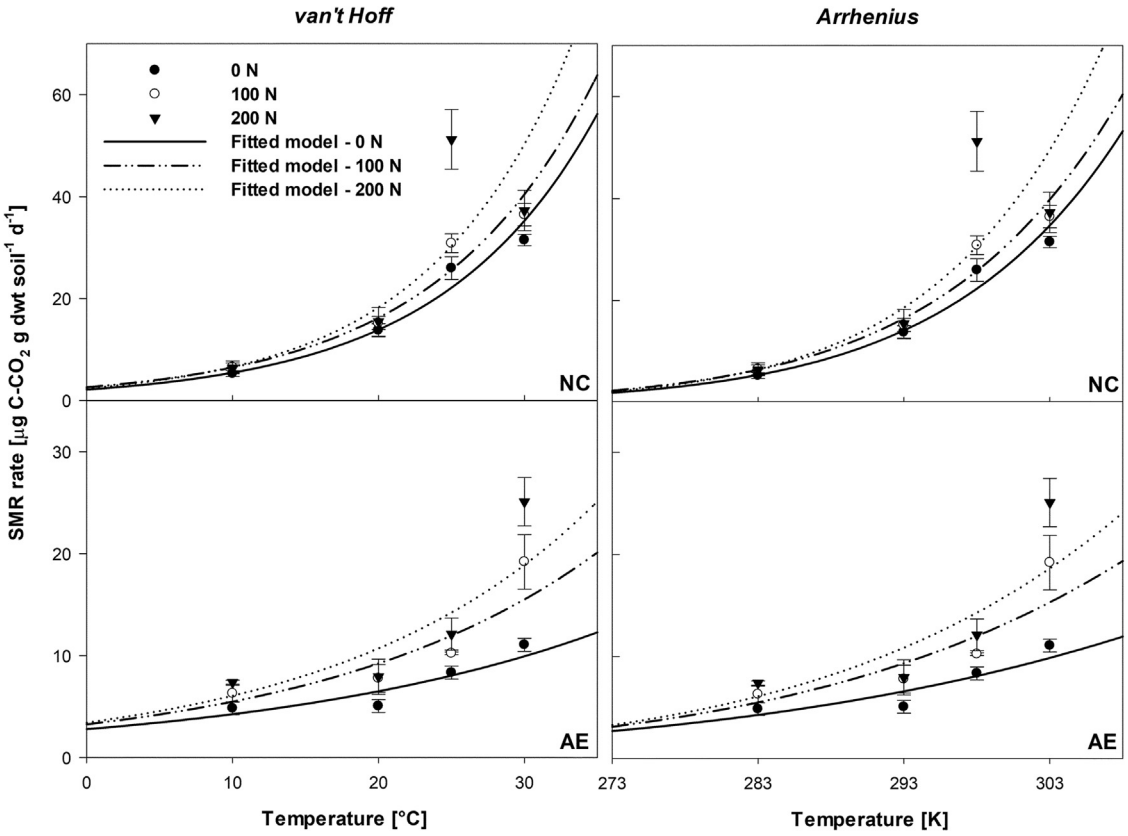

Fig. 2. Responses of soil microbial respiration (SMR) rate to different temperatures in control samples and under N additions (0 N, 100 N and 200 N in mg kg dwt soil^{-1}). Symbols indicate the average for each N treatment, under different temperatures, with the standard error (bars). Lines show the fitted models of van't Hoff (left) and Arrhenius (right) for control and N treatments in native Cerrado (NC) and agricultural ecosystem (AE).

Table 3
Model parameters (*b* or *Ea*), determination coefficient (R^2) and P value of the applied SMR rate-temperature models for NC and AE ecosystems of controls and N treatments.

Ecosystem	N (mg kg dwt soil^{-1})	van't Hoff			Arrhenius		
		b	R^2	P	*Ea*	R^2	P
NC	0	0.093	0.97	< 0.0001	66,369	0.97	< 0.0001
	100	0.091	0.95	< 0.0001	64,880	0.96	< 0.0001
	200	0.101	0.83	< 0.0001	72,240	0.84	< 0.0001
AE	0	0.042	0.77	0.0031	29,849	0.75	0.0002
	100	0.052	0.78	< 0.0001	36,540	0.77	0.0001
	200	0.057	0.71	0.0007	39,901	0.69	0.0006

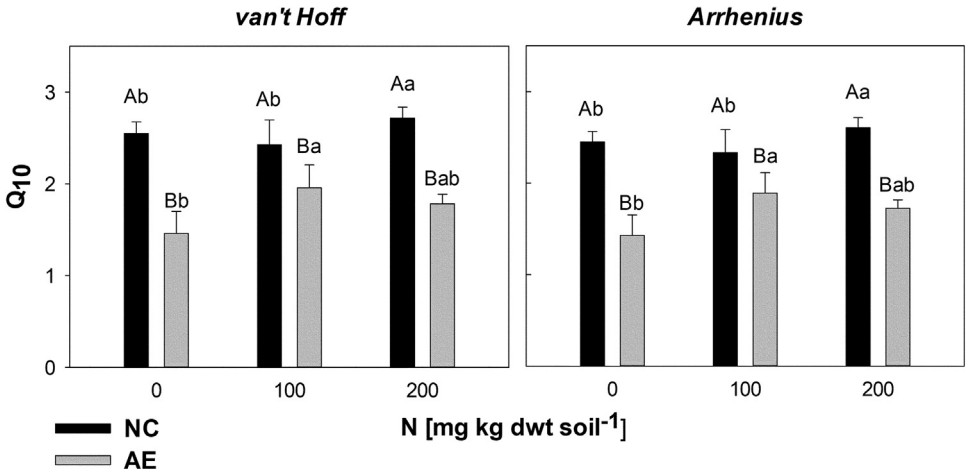

Fig. 3. Temperature sensitivity of soil respiration (Q_{10}) of 21 days obtained by van't Hoff and Arrhenius models in controls and N treatments for native Cerrado (NC) and agricultural ecosystem (AE). Error bars show the standard error of Q_{10}. Different capital letters between the sites in each N dose represent significant differences by Tukey's test ($P < 0.05$). Different lowercase letters between N doses for each site represent significant differences by the same test.

present high SOC and MBC content (Batlle-Bayer et al., 2010; Vinhal-Freitas et al., 2013). In agricultural soils, such as AE, SOC values are usually lower than in natural sites mostly due to tillage practices (Bayer et al., 2000).

SMR is an important indicator in the assessment of the soil functioning because it is strongly associated to the processes of decomposition and mineralization of soil organic matter (Hursh et al., 2017; Kirschbaum, 1995). In general, the results of this study show that NC presented greater SMR values than AE. In addition, NC also showed a higher Q_{10} than AE. These results agree with previously reported SMR in Brazilian Cerrado sites (da Silva et al., 2010; Frazão et al., 2010; Vinhal-Freitas et al., 2013). The lower Q_{10} values in AE are a result of the low organic matter level and less diverse microbial community present in this ecosystem in comparison with NC (Bandick and Dick, 1999; Vinhal-Freitas et al., 2013). This study also demonstrates that the ongoing conversion of native forests into agricultural lands affects SMR and its response to changes in temperature. Many studies reported that land use change to agricultural lands is the primary cause of soil degradation (Carvalho et al., 2014; Jiang et al., 2015; Wei et al., 2014; Zhang et al., 2015). The cultivation of monocultures combined with conventional tillage and the removal of aboveground vegetation decreases the soil microbial activity via an inefficient use of carbon by the microbiota (Anderson and Domsch, 1993, 1985; Kaiser et al., 2010). Forest soils function as large C stores (Yuste et al., 2003). Thus, after land use changes, CO_2 emissions increase and, simultaneously, SOC stocks decrease (Wei et al., 2014). A large part of global soil respiration is affected by agricultural land use, mainly due to tillage practices and the use of fertilizers. Therefore, more information is needed in order to enlighten the impact of soil management activities on the SMR function in tropical soils (Fiedler et al., 2015).

Our results indicate that the response of SMR to N additions depends on temperature and land use; indicating that it may affect soil microbial metabolism, altering CO_2 emissions. With regards the temperature dependence, this outcome is similar to the findings of other studies in tropical forests (Cleveland and Townsend, 2006). There have been studies that applied N additions with NH_4NO_3 as N source but mostly in temperate soils (Corre et al., 2003; Fang et al., 2017; Micks et al., 2004; Yoshitake et al., 2007). According to the study of Micks et al. (2004) in temperate forest soils, additions of NH_4^+ and NO_3^- either decreased or caused no change in SMR. Nevertheless, more information on N additions must be gathered in the tropical savanna soils (Copeland et al., 2012). The N deposition in soil is a great concern due to global warming and its consequence on terrestrial ecosystems. Natural and agricultural deposition of N may increase the soil carbon mineralization and, hence, increase CO_2 emissions to the atmosphere. Particularly, N fertilization of agricultural areas may also accelerate nitrous oxide (N_2O) emissions (Cui et al., 2016).

The SMR response to N inputs presented the highest value at 25 °C for NC and at 30 °C for AE - with 200 mg N kg dwt soil^{-1} addition. For NC, this may be explained by efficient use of N in this ecosystem due to higher SOC and a more diverse community. On the other hand, for AE, this could be caused by an adaption of the soil biota to a higher temperature, since this site is continuously exposed to solar radiation. In general, this result shows that N is a limiting factor of SMR, even though this microbial response depends on temperature. Temperature is believed to drive the adaptation of soil microorganisms (Classen et al., 2003; Fierer et al., 2006) and, thus, an increase in temperature may lead to a decrease in the efficiency of N use in NC. In cultivated sites, such as AE, temperatures are commonly higher than in NC (Licht and Al-Kaisi, 2005) and, thus, a selection of microorganisms that are acclimated to higher temperatures may occur (Peng et al., 2009).

Results show that van't Hoff and Arrhenius models can be applied to the studies in the SMR dependence on temperature in Cerrado sites because SMR rates increased exponentially with temperature. Warming experiments have admitted as a general relationship that SMR increases exponentially with temperature (Bekku et al., 2003; Karhu et al., 2014). Unlike other studies (Jenkins and Adams, 2011; Qi et al., 2002), there was no significant difference between the models used in all treatments. Better model fits occurred in controls than in N amendments. Although N additions increased the soil microbial activity, fit coefficients for both models decreased. The results also show the best model fits occur in NC, indicating that both models depend on studied sites. This can be explained by the higher levels of organic compounds and biomass (SOC and MBC) in the NC site in comparison to AE (Table 1), leading to higher SMR rates with an increase in temperature, hence, a better exponential fit. Further, the decrease in the model fits with N additions may be linked to changes in the microbial community (Li et al., 2017), affecting N use efficiency in soil systems.

Q_{10} values depended on the amount of N added and land use type. In this study, the Q_{10} values for NC ranged from 2.3 to 2.7. Many experiments have determined the Q_{10} factor in the forest soils in temperate ecosystems (Cable et al., 2008; Erhagen et al., 2015; Mielnick, 2000; Yuste et al., 2003). Reports on tropical Q_{10} values and in warmer regions are limited. Bekku et al. (2003) researched tropical soils from Malaysia and obtained Q_{10} values ranging from 2.1 to 2.7. In China, Peng et al. (2009) obtained Q_{10} values for forest soils that ranged from 1.09 to 5.51. Hence, our result for NC agrees with the values reported in the literature. Q_{10} values are also consistent with the median value of 2.4 from the worldwide literature summary (Raich and Schlesinger, 1992). Nevertheless, considerable variation has been found in published studies on the effects of temperature on soil respiration (Erhagen et al., 2015; Jenkins and Adams, 2011). These uncertainties in estimated Q_{10} values may be partly due to different modelling (Davidson and Janssens, 2006; Qi et al., 2002) and experimental conditions, such as temperature range (Chen et al., 2010), CO_2 determination (incubation or field data) (Subke and Bahn, 2010), and experimental duration of studies (short-term or long-term Q_{10}) (Bekku et al., 2003).

In addition, most Q_{10} literature is focused on forest ecosystems, and there is limited information on this factor in agro-ecosystems (Jiang et al., 2015; Zhang et al., 2015). Precise information on Q_{10} from agricultural ecosystems and the impact of management activities is needed for a better estimation of the global carbon cycle, and climate changes effects (Fiedler et al., 2015; Jiang et al., 2015; Liu et al., 2016). In the present study, agricultural practices decreased Q_{10} values significantly, with the values ranging from 1.4 to 2.0 in AE. In contrast, higher Q_{10} values were found for NC. This can be explained by the high organic matter quality and quantity; and higher species richness of microbial community in native forests (Jiang et al., 2015). These values are in agreement with the positive response of SMR to temperature increases in this ecosystem.

With regards N effects on Q_{10}, research performed in a subtropical forest in China by Tu et al. (2013), concluded that N additions decreased Q_{10} values of total soil respiration. In a study by Mo et al. (2008), high-N additions also decreased Q_{10} values for a mature tropical forest in China. In NC, the present study results diverge with these literature reports, because Q_{10} increased for a 200 mg N kg dwt soil^{-1} dose in comparison to NC control. However, 100 mg N kg dwt soil^{-1} addition did not significantly affect Q_{10} in NC. In AE, a different pattern is observed, since N input increased the Q_{10} value significantly when 100 mg N kg dwt soil^{-1} was added. The reason for a different response of both sites to this dose can be attributed to a selection of microorganisms better adapted to N inputs due to fertilization in AE, what does not happen for NC. Thus, the expressed Q_{10} values may reflect a change in the metabolism of soil microorganisms under N-rich situations (Tu et al., 2013). The results obtained in this research can be relevant to studies on soil function in tropical soils. However, more studies are necessary for assessing the CO_2 effluxes in native and agricultural ecosystems, including the effects of nutrient amendments on Q_{10}.

5. Conclusions

The comparative analysis of native Cerrado and agricultural ecosystem revealed that temperature and N additions had different impacts on SMR

and Q_{10} values. The temperature had more impact on SMR in NC than in AE, showing a major sensitivity of soil microbial activity in NC (Q_{10} values). There was no difference between the model quality of the applied van't Hoff and Arrhenius equations. Likewise, the derived Q_{10} values did not differ from each other. Nitrogen additions changed Q_{10} values, but its effect depends on the land use of the studied site and dose applied to the soil. Data from this work are important to understanding soil microbial functioning, and it can serve as a benchmark for future research in the Brazilian Cerrado on N deposition and its effect on CO_2 emissions from soils, which is crucial for mitigating climate change.

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Declarations of interest

None.

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